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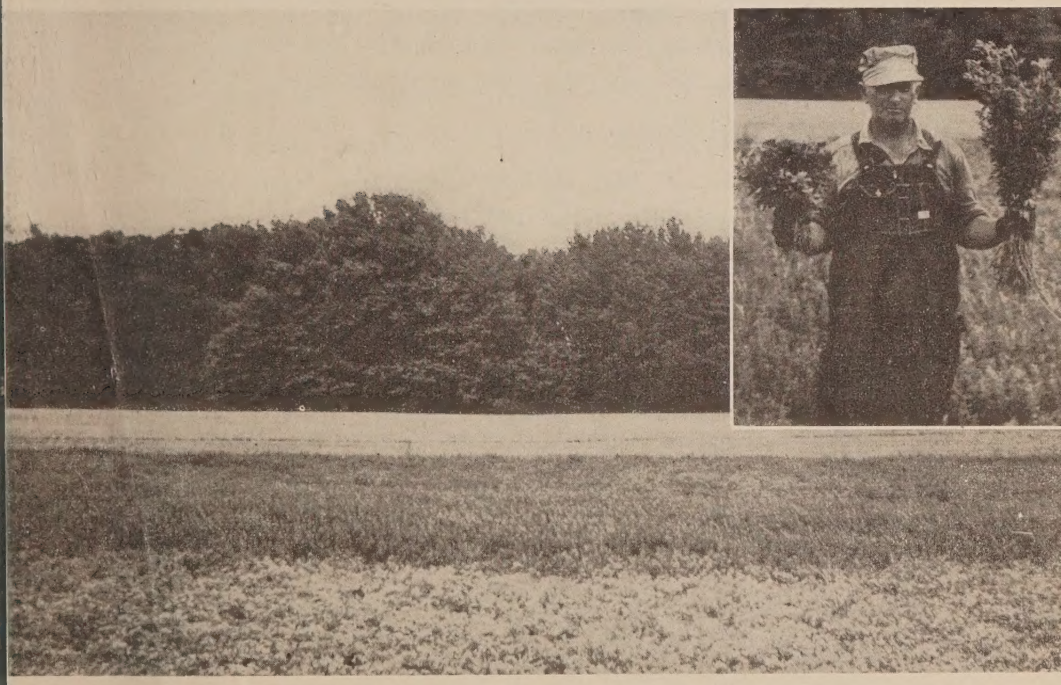
The Boron Needs of New Jersey Soils

By Eldrow Reeve, Arthur L. Prince, and Firman E. Bear



Effect of boron on color and growth of alfalfa on farm of E. H. Phillips, Cape May County. Dark strip treated—light sections untreated

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The Boron Needs of New Jersey Soils

ELDROW REEVE, *Research Fellow;* ARTHUR L. PRINCE, *Associate Soil Chemist;* AND FIRMAN E. BEAR, *Soil Chemist*[1]

Boron, like nitrogen, phosphorus, and potassium, is essential for the growth of plants. The natural source of this element in the soil is mostly the mineral tourmaline, a boro-aluminum silicate. In this form boron is only very slowly available for use, and it often becomes necessary, therefore, to apply borax ($Na_2B_4O_7.10H_20$), a water-soluble product containing, in its pure state, 11.34 per cent boron (B), if satisfactory crop yields are to be obtained.

Numerous cases of boron deficiency have been found in New Jersey within recent years. The correction of such deficiencies presents a difficult problem, because crops differ greatly in their need for boron as well as in their tolerance of this element. For some crops the range between optimum and toxic amounts of boron is very narrow. Furthermore, the amounts of borax required to correct deficiencies on the heavier types of soil are quite likely to cause crop injury if applied to the lighter soils. This bulletin is concerned with a survey of the boron needs of New Jersey soils and the boron requirements of New Jersey crops.

Turnip an Excellent Indicator-Plant for Boron Deficiency

Boron-deficient soils can be detected from the deficiency symptoms appearing on plants that are in need of the element; by applying borax and noting its effect on crop growth; or by testing the soil itself for water-soluble boron. All of these methods were used in this study.

Of the indicator plants for boron deficiency, the turnip is one of the best, because it has a relatively high boron requirement and the deficiency symptoms are easily identified on it. These symptoms consist of dark-brown, water-soaked areas, like those shown in the flesh of the turnip in figure 1. (Corresponding symptoms on the rutabaga, a close relative, are shown in figure 2.)

Accordingly, it was decided to prepare small packets of turnip seed and pass them out to farmers for sowing and observation. This was done during the summers of 1941 to 1943. Examination of the turnips on 156 of these small plots and on larger fields at harvest time of those years revealed boron-deficiency symptoms in 42 cases scattered over 14 counties of New Jersey.

Boron[2] Had Marked Effect on Crops on 40 Farms

In May, 1942, borax applications were made to 450 test plots located on approximately 350 farms that were well distributed over the State. The

[1]The authors wish to thank S. D. Gray, Northeast Manager of the American Potash Institute, for many helpful suggestions during the course of this study, and the Institute for partly financing the project. They are also very much indebted to Dr. John W. Shive for his advice and counsel and for two of the photographs reproduced in this bulletin. The county agricultural agents merit special mention for their cooperation in the field phase of this work, as do several of the larger canning companies and Dr. Edgar G. Rex, State Supervisor of Plant Pest Control.

[2]One pound or one part per million of boron is equivalent to 8.82 pounds or parts per million of borax, and one of borax to 0.1134 of boron.

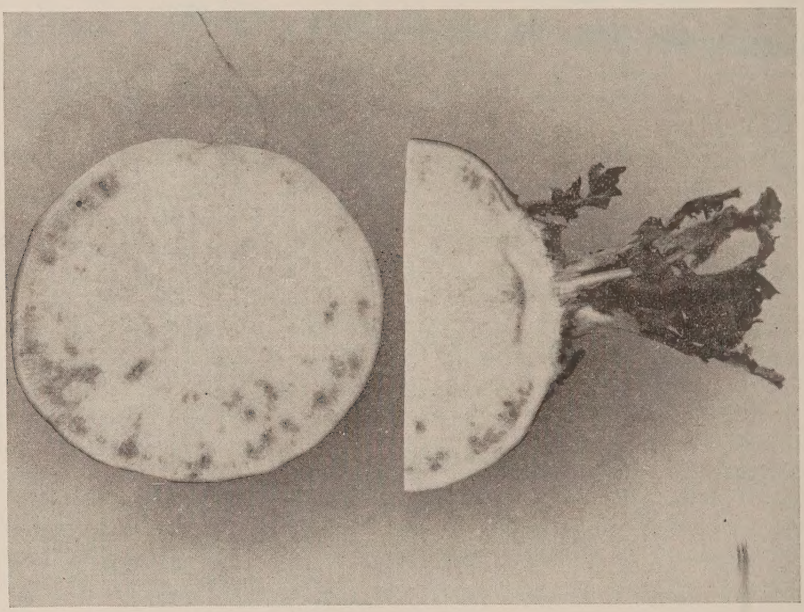

Fig. 2. Rutabaga From Boron-Deficient Soil

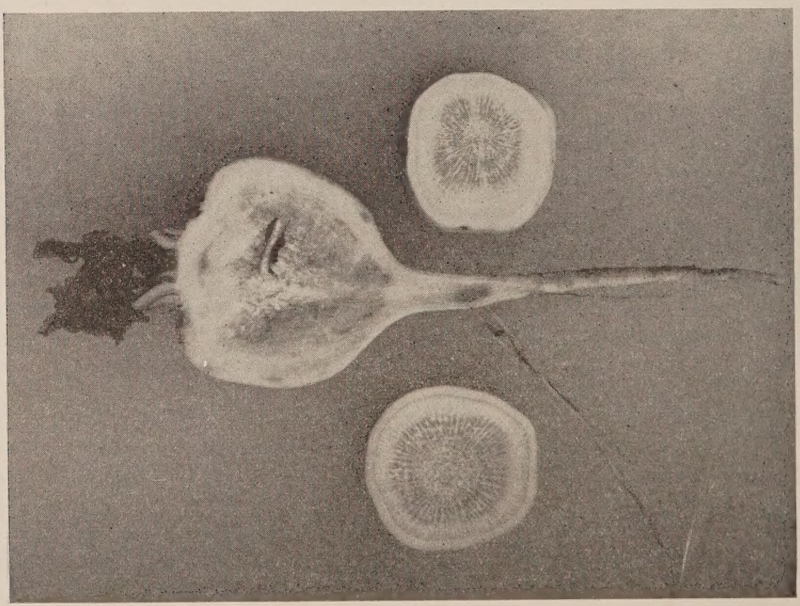

Fig. 1. Boron-Deficient Turnip

borax was applied broadcast with a cyclone hand-sower at the rate of 10 pounds per acre for all crops except alfalfa, the rate for which was 20 pounds per acre. A check of each plot in July and August showed that crops had responded to the borax treatment on 12 per cent of these farms. Injury was noted in only three cases, on snapbeans, radishes, and sweet potatoes, respectively, growing on very sandy soil. On these three plots, the borax was applied by the farmer himself, and the rate of application may have been heavier than was intended. Crop growth was visibly improved in 19 alfalfa, 16 tomato, and 3 spinach fields, and in 1 field each of eggplants, cucumbers, cabbages, and beets.

Plow-Depth Each Acre Should Contain 11 Ounces Soluble Boron

The amount of available boron in soils is measured by extracting the soils with hot water and determining the quantity of boron in the solution. But in order to draw a dividing line between soils that are adequately supplied with boron and those that are not, it is necessary to check these soil tests against plant tests. For greenhouse purposes, the sunflower is one of the best indicator plants for boron deficiency, because the young leaves of the plant become crinkled and discolored early in their growth cycle if the supply of this element is inadequate.

Some 200 samples of soil, chosen from an equal number of widely distributed New Jersey farms, were submitted to both the laboratory and the sunflower test to determine how much water-soluble boron had to be present to produce normal sunflowers and at what lower amounts the deficiency symptoms began to develop. As a result of this study it was decided that the dividing line between boron-adequate and boron-deficient soils should be set at 0.35 part of water-soluble boron per million parts of soil. On this basis, 88 of these 200 soils were found to be deficient in boron. In checking back to the fields from which these samples came and to the boron-deficiency symptoms that had been noted on the crops growing on these fields, surprisingly good agreement with this dividing line between boron adequacy and boron deficiency was observed. Since the laboratory test is much more quickly run than that in the greenhouse, it was decided to employ the laboratory test for the remainder of this work, and unless a soil was found to contain more than 0.35 part of boron per million of soil, an amount of boron equivalent to 11.2 ounces per acre to plow depth, it was classed as boron deficient.

Eight of 20 Important New Jersey Soils Deficient in Boron

Samples of the A and B horizons[3] of representative virgin profiles of 20 of the most widely distributed soil types in New Jersey, which are now under special study at the Experiment Station, were examined in the laboratory for total and water-soluble boron, and the results are shown in table 1. It will be noted that whereas the total boron content of the A horizon

[3]The surface-soil layer, usually extending below plow depth unless severely eroded, is spoken of as the "A horizon." The subsoil layer immediately beneath the A horizon is named the "B horizon."

and that of the B horizon of any given soil type were fairly similar, the differences among the several soil types were very great. Thus the variation in the A-horizon soil was between 18 and 110 p.p.m. and that in the B-horizon soil between 16 and 150 p.p.m. There was no correlation, however, between the amounts of total and water-soluble boron, the soil with the highest amount of total boron—Penn silt loam—being one of the lowest in the water-soluble form of the element. It will be observed that the A horizons of 8 of these 20 soil types contained not more than 0.35 part of water-soluble boron per million of soil and, therefore, were classed as boron deficient.

Table 1

*Boron Content of 20 Important New Jersey Soils**

Soil Type	Water-Soluble Boron		Total Boron	
	A Horizon	B Horizon	A Horizon	B Horizon
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
Sassafras sand	0.10	0.30	25	20
Sassafras loam	0.20	0.25	55	60
Washington loam	0.20	0.60	35	40
Penn silt loam	0.25	0.30	110	150
Chester loam	0.25	0.25	20	25
Gloucester stony loam	0.25	0.60	20	19
Sassafras loamy sand	0.30	0.25	30	30
Whippany silty clay loam	0.35	0.30	30	48
Hoosic stony loam	0.40	0.35	40	30
Fox gravelly loam	0.40	0.25	25	35
Bermudian silt loam	0.40	1.00	70	72
Lakewood sand	0.40	0.20	18	16
Merrimac silt loam	0.40	0.25	25	25
Colts Neck sandy loam	0.50	0.75	50	55
Lansdale silt loam	0.50	0.35	75	60
Papakating stony loam	0.50	0.35	55	50
Collington loam	0.50	1.00	65**	51
Dutchess shale loam	0.75	0.35	50	45
Hagerstown loam	0.75	0.20	40	45
Dover loam	1.00	0.20	30	25

*Except for the Bermudian, Dutchess, Fox, Hagerstown, and Hoosic, these represent virgin soils that have never been under cultivation.

**Another sample of Collington loam from a farm in the Freehold area, from which this sample also came, was found to contain 105 p.p.m. boron.

Lime Has Little Effect on Amount of Water-Soluble Boron

Previous work had shown that boron deficiencies are more likely to develop in well-limed soils than in those of the same type that have not received so much lime. This is in conformity with *the well-established principle of the calcium-boron relationship in plants, which is that any increase in the rate of absorption of calcium results in a decrease in the intake of boron and in the availability of this boron within the plant.*

As can be seen in table 2, the addition of lime did not reduce the solubility of the boron in the soil. It is certain, however, that it did reduce the availability of the boron to the plant. In confirmation of this point, our field studies showed that *plants growing on limed soils benefited much more from an application of borax than did those on unlimed soils.*

TABLE 2

Effect of Raising pH Value on Solubility of Boron in Four Soils

pH	Water-Soluble Boron Content*			
	Penn silt loam	Lansdale silt loam	Sassafras loam	Lakewood sand
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
4.5	1.27	1.25	1.50	1.50
5.0	1.25	1.25	1.55	1.50
5.5	1.30	1.30	1.50	1.50
6.0	1.32	1.25	1.50	1.50
6.5	1.18	1.27	1.52	1.50
7.0	1.18	1.23	1.50	1.50
7.5	1.20	1.20	1.48	1.45

*Two weeks after addition of 20 pounds of borax per 2 million pounds of soil.

Loams May Fix 10 Times As Much Boron As Sands

When boron is applied to the land, part of it becomes fixed by the soil and part remains in a soluble form in the soil solution. It is the portion remaining in solution that is of immediate value to the crop. From the data presented in table 3, obtained by measuring the loss of boron from a dilute solution of borax to which a representative sample of each soil type had been exposed, it is evident that the boron-fixing capacity of sands is much less than that of loam soils. The equivalent of one plowed acre of Lakewood sand, for example, had the capacity to fix the boron supplied by 9.6 pounds of borax, whereas Hagerstown loam had the capacity to fix 13 times that amount. It is apparent, therefore, that *a larger application of borax is required to correct a boron deficiency on loams than on sandy soils.* On the other hand, injury from excess borax is less likely to occur on the heavier loams than on the lighter types of soil. This fact is further demonstrated by the results of the experiment presented in table 4.

TABLE 3

*Boron-Fixing Power of 20 Important New Jersey Soils**

Soil Type	B fixed**	pH***	Soil Type	B fixed**	pH***
	mgm.			*mgm.*	
Sassafras loamy sand	0.25	4.4	Penn silt loam	5.00	4.5
Lakewood sand	0.50	4.4	Fox gravelly loam	5.00	7.4
Sassafras sand	0.70	3.9	Collington loam	5.30	4.7
Sassafras loam	3.00	4.4	Washington loam	5.30	4.6
Merrimac silt loam	3.00	4.4	Colts Neck sandy loam	5.50	4.3
Gloucester stony loam	3.30	5.4	Papakating stony loam	5.50	5.5
Dover loam	3.50	7.0	Bermudian silt loam	5.50	6.1
Chester loam	4.30	5.1	Lansdale silt loam	5.50	4.6
Whippany silty clay loam	4.30	5.9	Dutchess shale loam	6.40	7.0
Hoosic stony loam	4.70	6.9	Hagerstown loam	6.50	7.7

*A-horizon soil.

**Per kilogram of air-dried soil, in contact with a solution containing 11.34 mgm. B as borax.

***No correlation is shown between the pH and the fixation values.

The data in table 4 were obtained by adding borax to each of four soil types (Penn silt loam, Lansdale silt loam, Sassafras loam, and Lakewood sand) at rates of 5, 10, 20, and 40 pounds per 2 million pounds of soil. After standing for 2 weeks under conditions of optimum moisture, each sample

Table 4

Increase of Water-Soluble Boron in Borax-Treated Soils

Treatment . . . *lbs. borax per acre*	5	10	20	40
	Water-Soluble Boron			
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
Penn silt loam	0.15	0.27	0.90	1.85
Lansdale silt loam	0.10	0.22	0.85	1.60
Sassafras loam	0.20	0.45	1.20	2.10
Lakewood sand	0.20	0.57	1.20	2.20

was analyzed for water-soluble boron. The increase resulting from the respective borax treatments, on each of the four soil types, was obtained by subtracting the water-soluble boron content of the untreated soil from that of the treated sample. It will be noticed that the increase was considerably greater for Lakewood sand and Sassafras loam than for the two heavier soils, Penn silt loam and Lansdale silt loam.

Borax-Sensitive Plants Absorb Large Amounts of Boron

An experiment was conducted in the greenhouse to determine the differences in the total boron content of 11 of the State's most important crop plants (alfalfa, cabbage, carrot, clover, corn, sweet potato, white potato, soybean, spinach, tomato, and turnip) and of sunflowers, and the effect of a 20-pound-per-acre application of borax on the yield and boron content of these plants. The experiment was carried out in 2-gallon pots, each containing 20 pounds of air-dry Sassafras loam soil. The borax was applied in solution to the surface, and no attempt was made to mix it with the bulk of the soil. Plants were grown from seed, except for the white potato and sweet potato, of which uniform seed pieces and sprouts, respectively, were transplanted to the pots. The seedlings were thinned so that a given crop was represented by the same number of plants, in both the treated and the untreated pots. After the plants had grown for about one month, the entire above-ground parts were harvested, dried, and milled for boron determinations. It was necessary to harvest the various types of plants at different times, however, in order to have them at a comparable stage of physiological development. The total boron contents of the plants from the treated and the untreated soil, together with the percentage increase in yield due to the use of borax, are shown in table 5.

The soybean, sweet potato, and sunflower plants growing in the soil that had been treated with borax at the rate of 20 pounds per acre developed boron-toxicity symptoms. It will be noted that these three plants had the highest concentration of boron, when grown on both the boron-treated and

the untreated soil. This is an interesting observation, since boron-toxicity symptoms are readily developed on all three plants. It would appear, therefore, that these plants have the faculty of readily absorbing boron and of building it up to toxic concentrations in their tissues.

TABLE 5

Variation in Boron Content of 12 Important Plants

Plant	Boron Content of Plants		Yield Increase Due to Borax
	Untreated soil	Borax-treated soil*	
	p.p.m.	*p.p.m.*	*per cent*
Corn	16	44	2
Carrots	40	64	86
Cabbage	40	117	153
Alfalfa	44	146	5
Potato	44	125	—6**
Turnip	44	125	46
Spinach	44	125	75
Clover	48	104	23
Tomato	48	125	85
Soybean	58	206***	11
Sweet potato	73	217***	10
Sunflower	75	187***	0

*Borax applied at rate of 20 pounds per acre.
**Indicates per cent decrease in yield.
***These plants showed boron-toxicity symptoms.

It will be observed that, on the untreated soils, the sunflower had the highest boron concentration of any of the 12 plants tested. Grown under conditions of extreme crowding, the plant rapidly depletes the boron supply of a soil that is naturally low in the element and quickly develops the symptoms. Except for the potato, increase in yield of all the other crops resulted from the use of borax, the greatest response occurring with cabbage. Corn, however, has a very low content of boron and responded very little to the application of borax. Our experiments have shown that oats and wheat also require very little boron, and this is probably true of all the grasses.

Boron Readily Leached from Soil

From the standpoint of field practice it is important to know the rate at which boron is removed from the soil. The two most important means of boron loss from the soil are through leaching by rain and extraction by plants.

An experiment was conducted in the laboratory to determine how much boron would be lost by leaching a 7-inch depth of soil with water equivalent to one-fourth the 44-inch average annual rainfall of New Jersey. Four soil types (Penn silt loam, Lansdale silt loam, Sassafras loam, and Lakewood sand), with which borax equivalent to 20 pounds per 2 million pounds of soil had been mixed, were used in the test. Distilled water was added to each

pot to bring its moisture content to the optimum, and the pots were allowed to stand for one week before the leaching was begun. Enough distilled water was then added every other day to yield 1 liter of leachate from each pot. This was continued until 9 liters of leachate (equivalent to 11 inches of rainfall) had been collected. This leachate was analyzed for boron and the results are presented in table 6.

Table 6

Boron Losses Resulting from Leaching Soils with Water

Soil Type	B Added to Soil*	B Leached from Soil**
	mgm.	*mgm.*
Penn silt loam	8.49	6.07
Lansdale silt loam	8.49	6.30
Sassafras loam	8.49	6.52
Lakewood sand	8.49	7.20

*Equivalent to an application of 20 pounds of borax per acre.
**By an amount of water equivalent to a depth of 11 inches.

It will be noted that approximately 75 per cent of the boron supplied by the equivalent of a 20-pound-per acre application of borax was removed from the three heavier soil types by leaching with a depth of water equal to one-fourth that of the average rainfall of New Jersey, and 85 per cent from the sandy soil.

The soundest and most economical method of handling the problem of boron deficiency in the field would seem to be to add moderate amounts of borax to the soil each year instead of larger amounts every third or fourth year. In this way, danger from excess boron would be avoided and losses by leaching would be minimized. Such yearly use of borax should not result in great accumulation of boron, since any excess would normally be carried away in the drainage water.

Green Manures Increase Water-Soluble Boron in Soil

An experiment was conducted to determine the extent to which plowing under of green manures would alter the water-soluble boron content of Penn silt loam, Lansdale silt loam, Sassafras loam, and Lakewood sand. Finely chopped young green domestic ryegrass, equivalent to 12 tons per 2 million pounds of soil, was thoroughly mixed with a given amount of each of the four soil types. A similar mixture was made with sweet clover instead of ryegrass. The soils were adjusted to their optimum moisture contents and allowed to stand at 80° F. for one month. At the end of this period each soil was analyzed for water-soluble boron, and the value compared with that obtained from an analysis of the untreated soil. The increases in water-soluble boron resulting from the two treatments on the respective soils are presented in table 7.

TABLE 7

Increase in Water-Soluble Boron in Soils from Use of Green Manures

Soil Type	Green Manure*	Increase in B
		p.p.m.
Penn silt loam	Ryegrass	0.11
	Sweet clover	0.13
Lansdale silt loam	Ryegrass	0.07
	Sweet clover	0.10
Sassafras loam	Ryegrass	0.09
	Sweet clover	0.10
Lakewood sand	Ryegrass	0.04
	Sweet clover	0.05

*Green manure added at rate of 12 tons per acre (2 million pounds of soil) and allowed to decompose for 1 month.

As the data in table 7 show, the amount of water-soluble boron was materially increased during the process of decomposition of the green plant material in the soil. Sweet clover gave a slightly higher increase in water-soluble boron than did ryegrass. The greatest increase was obtained in Penn silt loam, and the least in Lakewood sand. Undoubtedly the organic acids, formed in the decomposition of the plant materials, attack the less soluble forms of boron in the soil, rendering them more soluble. It is, of course, obvious that the *total* boron content of a soil cannot be increased by plowing under a green manure crop produced on that soil.

Organic Materials Not Adequate Source of Boron

Nine organic materials were examined in the laboratory for their total boron content. The results are listed in table 8. It is clear, from these data, that it would require a good many tons of these organic materials to supply an amount of boron equivalent to 10 pounds of borax. Nevertheless, the regular use of manure should reduce the need for adding borax, since the manure not only contains small amounts of soluble boron but, on decaying in the soil, speeds up the dissolving of the boron minerals. On many soils and for many crops, however, it becomes necessary to apply borax in amounts up to 40 pounds per acre and, in such cases, it is out of the question to rely on manure or other organic materials as the sole source of boron.

TABLE 8

Boron Content of Nine Organic Materials

Organic Material*	Boron Content	Needed to Supply B Equal to 10 lbs. Borax
	p.p.m.	*tons*
Animal tankage	45	12
Alfalfa hay	41	14
Cocoa tankage	37	15
Milorganite	33	17
Beetle, molded-scrap**	29	19
Chicken manure	20	28
Bovung	20	28
Cottonseed meal	10	56
Wheat straw	7	94

*All data calculated on basis of dry weight.
**A plastic product.

Root Crops Have Special Need for Extra Boron

In April, 1943, carrots on the farm of Charles and George Max, Passaic County, were treated with borax at an average rate of 10 pounds per acre. The borax was applied broadcast, just after the carrots had been planted. At harvest, yields were taken, and the results are given in table 9. It would appear, from the increased yields of almost 3 tons per acre, that borax was an important factor in carrot production on the Wethersfield loam soil on this farm.

Table 9

Effect of Borax on Acre Yield of Carrots in Passaic County*

Borax per Acre	Marketable Carrots
lbs.	*lbs.*
0	23,855
10	29,826

*It has been reliably reported that, when they had a choice, wild rabbits ate the carrots growing on a borax-treated plot of land in preference to those on untreated soil.

The root crops in general, are known to have a relatively high boron requirement. Turnips and rutabagas are especially sensitive to boron deficiency, as previously noted. Although field tests were not conducted to determine the effect of borax on yields of beets and radishes, it is known that many New Jersey truck growers are applying between 20 and 30 pounds of borax per acre in preparation for growing these and other root crops.

Ten Pounds of Borax Increased Spinach Yield 20 Per Cent

On April 28, 1943, spinach, growing on Merrimac loam soil on the farm of John Talakowitz, Passaic County, was treated with borax, applied broadcast at rates of 5 and 10 pounds per acre. At harvest time yield data were obtained from treated and untreated areas of the field, and the results are shown in table 10. It will be noticed that marked increases in yield resulted from both rates of application, but the 10-pound rate was the more effective, giving an increase of over 6,000 pounds of spinach per acre.

Table 10

*Effect of Borax on Acre Yield of Spinach in Passaic County**

Borax per Acre	Yield
lbs.	*lbs.*
0	21,054
5	23,232
10	27,588

*The farm on which this test was made is under irrigation.

Red-Clover Seed Yield Doubled by Use of Borax

On June 13, 1942, Kentucky 101 red clover, growing on Penn shale loam on the farm of Boyd Fullerton, of Somerset County, was treated with borax to determine its effect on seed production. A 16-acre field of the clover was divided into four plots of equal size. The whole area was given a top-

dressing of 500 pounds of 0-12-12 fertilizer per acre immediately after the first crop had been harvested for silage. Three of the plots received, in addition, 20-,40-, and 60-pound treatments, respectively, of borax per acre, the material being applied in conjunction with the fertilizer. The data on seed production in table 11 show that the yield was nearly doubled by the use of 40 pounds of borax per acre. The 20-and 60-pound applications were somewhat less effective than the 40-pound treatment.

Table 11

Effect of Borax on Acre Yield of Kentucky 101 Red Clover Seed

Borax per Acre	Seed Yield
lbs.	*lbs.*
0	97
20	145
40	190
60	152

Alfalfa Yields Greatly Increased by Borax Treatment

On April 21, 1943, alfalfa fields on the farms of Robert Jones and H. H. Schaper, Cumberland County, were treated with borax, applied broadcast at the rates of 10, 20, and 40 pounds per acre. The increases in yields resulting from the respective borax treatments, for the season, on these two farms are shown in table 12. The 40-pound-per-acre application of borax resulted in an increase of more than 1 ton of dry alfalfa hay per acre on the Jones farm. The 20-pound application also gave substantial increases in yields on both farms, but 10 pounds per acre was inadequate for alfalfa on these soils.

In 1943, yield data were also obtained on two alfalfa fields that had been treated with borax, at the rate of 20 pounds per acre, on May 5, 1942. These fields were on the farms of E. H. Phillips and Milton Westcott, Cape May County. The second crop was far below normal, and what would have been the third crop failed to start because of the extended drought in that section of the State. It will be noticed, however, that 20 pounds of borax per acre gave large increases in yield on each of these farms. On the Phillips farm the increase amounted to 1 ton of dry alfalfa hay per acre, and on the Westcott farm to three-quarters ton. The alfalfa on the untreated areas on both farms was stunted and yellow, whereas that on the treated area was quite normal.

Boron Deficiency in Alfalfa Indicated by "Yellows"

The extremely yellow alfalfa fields so frequently seen in southern New Jersey can, in most instances, be attributed to an inadequate supply of boron in the soil, to injury by leafhoppers, or both. With a little experience, it is easy to distinguish the discoloration resulting from a lack of boron from that caused by leafhoppers. Yellow leaves resulting from leafhopper injury may occur at any position on the shoots, whereas the yellowing or reddening caused by boron deficiency is always confined to the tip leaves, whether

Table 12

Effect of Borax on Acre Yield of Alfalfa Hay on Four Farms

Treatment . . . *lbs. borax per acre*	0	10	20	40
	Alfalfa Hay*			
	lbs.	*lbs.*	*lbs.*	*lbs.*
Cumberland County—Sassafras sandy loam				
Robert Jones farm				
First cutting	2337	2175	3135	3561
Second cutting**	1719	2119	1888	2495
Third cutting**	1119	1270	1530	1625
Total for season	5175	5564	6553	7681
H. H. Schaper farm				
First cutting	3178	3242	3380	3637
Second cutting**	1418	1803	2121	1760
Third cutting**	640	898	854	1025
Total for season	5236	5943	6355	6422
Cape May County—Sassafras loamy sand				
E. H. Phillips farm				
First cutting	2026	....	3628	....
Second cutting	1365	....	1748	....
Total for season	3391	....	5376	....
Milton Westcott farm				
First cutting	2100	....	3242	....
Second cutting	1056	....	1439	....
Total for season	3156	....	4681	....

*Yields of oven-dry hay.

**As a result of extreme drouth in south Jersey in July and August, 1943, the second and third cuttings were far below normal.

they be on the side or the main branches. In the summer of 1943 many alfalfa fields in southern New Jersey showed definite boron-deficiency symptoms. The deficiency is generally much more severe in dry than in wet seasons.[4]

Nearly 2 Pounds of Borax Absorbed per Ton of Alfalfa Hay

Seven crops of alfalfa hay were grown in pots in the greenhouse on four soils—Penn silt loam, Lansdale silt loam, Sassafras loam, and Lakewood sand. At the start, borax was added at the rate of 5 pounds per acre to the Lakewood sand, and 20 pounds per acre to each of the other three soils. The several harvests were carefully weighed and analyzed for their boron content, yielding the data in table 13. It will be noted that the boron concentration in the alfalfa decreased successively through the first five harvests. The sixth crop in each case showed a marked increase in boron concentration, followed by a decline in the seventh. It will also be noted that a little

[4]The deficiency often develops just after the drouth has been broken by a good rain, after which the crop grows so rapidly that its roots are unable to obtain boron, from a soil inadequately supplied with the element, at a sufficiently rapid rate to meet its needs. Under continuously good weather conditions the deficiency may not be apparent but, nevertheless, the crop may respond to an application of borax.

over half as much boron as had been added to the Penn, Lansdale, and Sassafras soils at the beginning of the test was removed in the seven crops, whereas the amount contained in the alfalfa harvested from the Lakewood sand was equal to that added at the start.

TABLE 13

*Boron Content of Alfalfa from Seven Successive Harvests**

Soil Type	Boron Content of Alfalfa Hay						
	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5	Harvest 6**	Harvest 7
	p.p.m.	*p.p.m*	*p.p.m*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Penn silt loam	156	106	103	101	100	173	166
Lansdale silt loam	156	113	108	106	103	166	166
Sassafras loam	125	108	106	100	83	125	116
Lakewood sand	133	108	91	83	75	216	183

*Plants grown in pots in the greenhouse. Borax added at rate of 5 pounds per acre to Lakewood sand and at 20 pounds to each of the other soils.

**In checking back through the records to find a possible explanation for the great increase in boron content of the sixth crop, it was found that shortly after the fifth crop had been removed, borax was spread broadcast over the floor of the greenhouse to control weeds. Undoubtedly, the fine dust that always accompanies a broadcast application of borax, settling on the plants and soil in the pots, was responsible for the sudden increase in the boron content of the sixth crop of alfalfa. Two other experiences serve to illustrate the potency of minute amounts of borax on plant growth. Small stones, stored in the corner of this same greenhouse, that were subsequently rinsed thoroughly with water, placed in the bottom of tin cans, and covered with soil caused marked toxicity on sunflowers. The plants grew normally until the roots penetrated to the depth at which the stones had been placed and then showed severe injury, definitely indicating that the boron was coming from the stones. Soybeans grown in a soil that had been screened and mixed on a carefully swept concrete floor, previously in contact with borax, developed definite boron-toxicity symptoms.

The constancy of the boron content of alfalfa hay grown on 20 different soil types, under conditions of an adequate supply of the element, is apparent from table 14. Approximately 1.8 pounds of borax was found per ton of alfalfa hay. Thus, if a fertilizer containing 30 pounds of borax per ton were used on alfalfa at the rate of 500 pounds per acre, a 4-ton harvest of alfalfa would remove nearly all of the applied borax.

Boron Deficiency Observed on Apples in Passaic County

On a visit to his father's farm at Hawthorne, in Passaic County, New Jersey, in the summer of 1941, Charles Blasberg, Research Horticulturist of the Vermont Agricultural Experiment Station, diagnosed a trouble on Dutchess apples as boron deficiency, similar to that which occurs in Vermont. An inspection of the fruit showed typical external and internal symptoms of boron deficiency on apples of that variety: the skins of the fruits were cracked and their interiors showed the well-known brown "cork." Considerable die-back and yellowing[5] were apparent on Rome trees in the orchard, and rosetting of the leaves was conspicuous on the McIntosh variety. Broadcast applications of borax were made since around certain trees in this orchard at the rate of one-half pound per tree, but the experimental data were not adequate at the end of the 1943 season to indicate to what extent this condition can be remedied by such treatments. The orchard is on Merrimac soil.

[5]This yellowing may have been due to nitrogen deficiency rather than to a lack of boron.

Table 14

Boron Content of Alfalfa from 20 Soil Types*

Soil Type	Yield of Dry Matter		Boron (B)	Boron Calculated as Borax	
	Per pot	Per acre		Per acre	Per ton
	gm.	*tons*	*per cent*	*lbs.*	*lbs.*
Lakewood sand	22.9	2.8	0.0092	4.50	1.61
Sassafras loamy sand	23.8	2.9	0.0108	5.56	1.92
Papakating stony loam	26.1	3.2	0.0113	6.35	1.98
Sassafras sand	29.1	3.6	0.0092	5.82	1.62
Whippany silty clay loam	29.9	3.7	0.0097	6.26	1.69
Hagerstown loam	36.2	4.4	0.0087	6.79	1.54
Fox gravelly loam	38.6	4.7	0.0100	8.29	1.76
Chester loam	39.4	4.8	0.0100	8.47	1.76
Gloucester stony loam	40.1	4.9	0.0100	8.64	1.76
Lansdale silt loam	40.4	4.9	0.0120	10.41	2.12
Merrimac silt loam	41.0	5.0	0.0113	9.97	1.99
Bermudian silt loam	46.3	5.6	0.0092	9.17	1.64
Dover loam	46.6	5.7	0.0108	10.85	1.90
Colts Neck sandy loam	48.6	5.9	0.0100	10.50	1.78
Penn silt loam	50.4	6.2	0.0117	12.70	2.05
Hoosic stony loam	53.6	6.6	0.0100	11.55	1.75
Collington loam	56.4	6.9	0.0100	12.17	1.76
Sassafras loam	56.6	6.9	0.0100	12.17	1.76
Washington loam	59.4	7.3	0.0100	12.79	1.75
Dutchess shale loam	67.3	8.3	0.0097	14.11	1.70

*Composite of seven harvests from greenhouse pots.

Table 15

Variation in Water-Soluble Boron Content of 176 New Jersey Farm Soils

Soil Type	Number of Samples	Range in B Content*	Acreage in State
		p.p.m.	
Sassafras sandy loam	70	0.10 to 0.87	138,000
Sassafras sand	35	0.10 to 0.87	456,000
Sassafras loam	9	0.15 to 0.87	168,000
Penn silt loam	9	0.15 to 0.70	123,000
Merrimac sandy loam	7	0.25 to 0.62	17,000
Lansdale silt loam	7	0.25 to 0.68	40,000
Dover loam	6	0.37 to 1.00	25,000
Dutchess shale loam	5	0.37 to 0.75	62,000
Gloucester stony loam	6	0.15 to 0.30	108,000
Washington loam	4	0.20 to 0.75	7,000
Chester loam	4	0.25 to 0.50	15,000
Fox gravelly loam	4	0.37 to 0.40	4,000
Hagerstown loam	3	0.31 to 0.75	23,000
Merrimac loam	3	0.10 to 0.40	17,000
Collington loam	2	0.37 to 0.50	40,000
Lakewood sand	2	0.15 to 0.40	234,000

*It seems probable that borax, as a constitutent of mixed fertilizer, has been applied to many of these soils.

Boron Deficiency Widespread on Sassafras Soils

In table 1, the twenty important New Jersey soils are listed in the order of the amount of water-soluble boron in their A horizons. The need for supplemental boron under field conditions, however, does not necessarily

follow this same order, since most of these samples were from virgin-soil areas that had never been subjected to the rigors of cultivation. Records of boron determinations on about two hundred samples of soil chosen from cultivated fields that were widely distributed over the State (table 15) and results obtained from many field tests indicate that the Sassafras soils, which figure prominently in the agriculture of southern New Jersey, are conspicuously deficient in boron, and crops growing on these soils usually show marked response to borax treatment. Lakewood sand, another south Jersey soil, is also likely to require additional boron for best results. On the other hand, Collington soils, occurring principally in Monmouth and Burlington Counties, have little need for borax because the greensand marl that is present in them has a very high boron content[6]. Crops growing on the Penn soils, prominent in central New Jersey, have frequently been considerably improved by the use of borax. In northern New Jersey, the soils in greatest need of boron are those belonging to the Merrimac, Gloucester, and Wethersfield series. Crops growing on the Dutchess, Washington, Dover, and Chester series were not benefited by the use of borax.

Occasional Potato Soil May Need Extra Boron

Since a large percentage of the potatoes in New Jersey are grown on Sassafras soils, it is possible that a lack of boron may occasionally be a limiting factor in the production of this crop. No dependable evidence of any beneficial effect from the use of borax was found, however, in field tests that were conducted on the potato farm of Spencer Perrine at Cranbury. These tests consisted in using borax at the rate of 20 pounds per acre in the fertilizer that was applied in bands along the row at planting time. The data obtained were not sufficiently decisive to warrant drawing any conclusions. In checking up on the fertilizer it was found that it had been manufactured by a company that adds 5 pounds of borax to every ton of its mixture. Since fertilizer is used on this farm at the rate of one ton per acre, and potatoes have been grown year after year with few intervening crops, doubt arose whether the soil, a Sassafras loam, was actually deficient in boron. Examination of a representative sample of the field showed a water-soluble boron content of 0.80 p.p.m. of soil, over twice the 0.35 p.p.m.[7] set as the dividing line between deficiency and non-deficiency.

In another part of the same field, two 10-pound-per-acre applications of borax in water solution were sprayed on the potato foliage without apparent effect. The supplemental test was made because it was thought that if a crop shows a need for boron during the growing season it might be easier to correct the deficiency by using borax as a spray for the plants rather than as a dry salt applied to the soil.

[6]Samples of greensand marl examined in this laboratory have shown a total-boron content ranging between 385 and 480 p.p.m. One sample of Keansburg loam, a soil having a high content of greensand marl, was found to contain 245 p.p.m. boron. This soil sample came from the Camden area.

[7]This value of 0.35 p.p.m. boron applies to crops that do best at pH values above 6, but it may be higher than is necessary for potatoes and sweet potatoes grown on acid soils.

Boron Deficiency Symptoms Observed on New Jersey Crop Plants

- *Alfalfa*: See page 13.

- *Cabbage*: The leaves of plants that have become deficient in boron after the head has begun to develop usually droop and have a wilted appearance. If the head is fairly well developed, the outer leaves separate from the stem and the head appears yellow. But if the head has not yet started to develop, the leaves are curled and the head fails to form. The center of the main stalk usually shows brown spots, especially near the top.

- *Cauliflower*: The most striking boron-deficiency symptom of cauliflower is the browning of the head, which is usually associated with hollow stems showing discoloration on the cavity wall.

- *Celery*: Boron deficiency of celery is known as cracked-stem, and shows first in a brownish mottling of the leaves. Later, crosswise cracks appear on the surface of the stalk and the tissue curls outward from these breaks, making the stalk very rough to the touch.

- *Clover*: The most pronounced symptom is a red coloration, sometimes with a purplish tint, affecting first the margins on the tip half of the leaves. Affected leaves are distributed over the entire plant, the condition being most marked in the younger parts.

- *Corn*: Young leaves fail to unroll properly, and white areas appear on them. These areas look as if someone had scratched out the green material with a pin. In the field, boron-deficiency symptoms of corn are most likely to appear in the first two weeks of growth, and then to disappear as the plants grow older.

- *Eggplant*: Boron deficiency symptoms have not been identified under field conditions, but the crop has shown consistent response to borax treatment.

- *Lettuce*: Boron deficiency is characterized by malformation of the more rapidly growing leaves, by spotting and burning of their tips, and by death of the growing point of the plant.

- *Potato*: Distinct boron-deficiency symptoms on this crop have not been observed in the field.

- *Pumpkin*: The outstanding symptoms are the rings that form on the leafstalks, giving them an accordion-like appearance and making them very brittle.

- *Root Crops—Table Beets, Rutabagas, Radishes, Turnips*: The symptoms, commonly known as brown-heart, may appear as dark spots on the surface of the root, but more frequently as dark-brown water-soaked areas in the flesh of the root, as shown in figure 1 and 2.

- *Spinach*: The leaves are smaller than normal and are somewhat deformed.

● *Sweet Potato*: Plants grown in the greenhouse without borax produced potatoes having dark-streaked centers. Clear-cut boron-deficiency symptoms have not been observed in the field.

● *Tomato*: The first indication of boron deficiency in tomatoes may occur either on the terminal leaflets or on the bottom or oldest leaves of the plant. The growing tips curl inward and become yellowish. On the older leaves, the first evidence is a yellowing of the tips, and the veins in the affected areas turn pink. The stems become very brittle and break easily on handling.

● *Apple*: The four major symptoms of boron deficiency in the apple are

Internal Cork: Brown areas, large or small, occur at any point within the flesh of the fruit. If internal cork starts early and is severe, the apples are dwarfed or bumpy, or both. If it starts in late summer, as is more common, the apples are smooth or slightly pebbly, of normal size, and subject to early dropping.

External Cork: The skin of the apple dies and its surface becomes reddish or yellowish brown and develops cracks. External cork is often confused with frost or spray injury.

Dieback: The tip leaves of the twigs turn a reddish bronze in July and August, and the twigs die from the tip backward.

Rosette: Dwarfed, narrow, stiff, brittle leaves are often found in a tuft at the end of a twig that is otherwise bare. Such leaves in other locations on the tree are also indicative of boron deficiency.

Boron Toxicity Symptoms Easily Identified

Certain crops, such as snapbeans, limas, soybeans, and sweet potatoes, are readily injured by an overdose of borax. Injury from excess boron shows first as yellowish brown spots around the edges of the leaves. The lower or older leaves are usually affected first and, in severe cases, the brown spots may be distributed over the entire leaf surface.

It will be recalled that injury from an excess of boron was experienced during the first World War as a result of the use of poorly refined potash salts containing considerable amounts of borax as an impurity. This situation was quickly corrected by improvement in refining processes until, today, the potash salts used in agriculture are virtually borax-free, varying from none to approximately ¾ per cent of sodium tetraborate.

Evidence of Boron Deficiency in Every New Jersey County

The several symbols shown on the map in figure 3 indicate the approximate location of farms on which evidence of boron deficiency was found. The crosses represent farms on which turnips developed boron-deficiency symptoms in 1942 and 1943; the circles indicate farms in which alfalfa showed boron deficiency symptoms in 1943; the black dots locate farms on which crops were benefited by applications of borax; and the black triangles show the position of other farms, samples of soil from which showed water-soluble boron of less than 0.35 p.p.m. It will be noted that every county in the

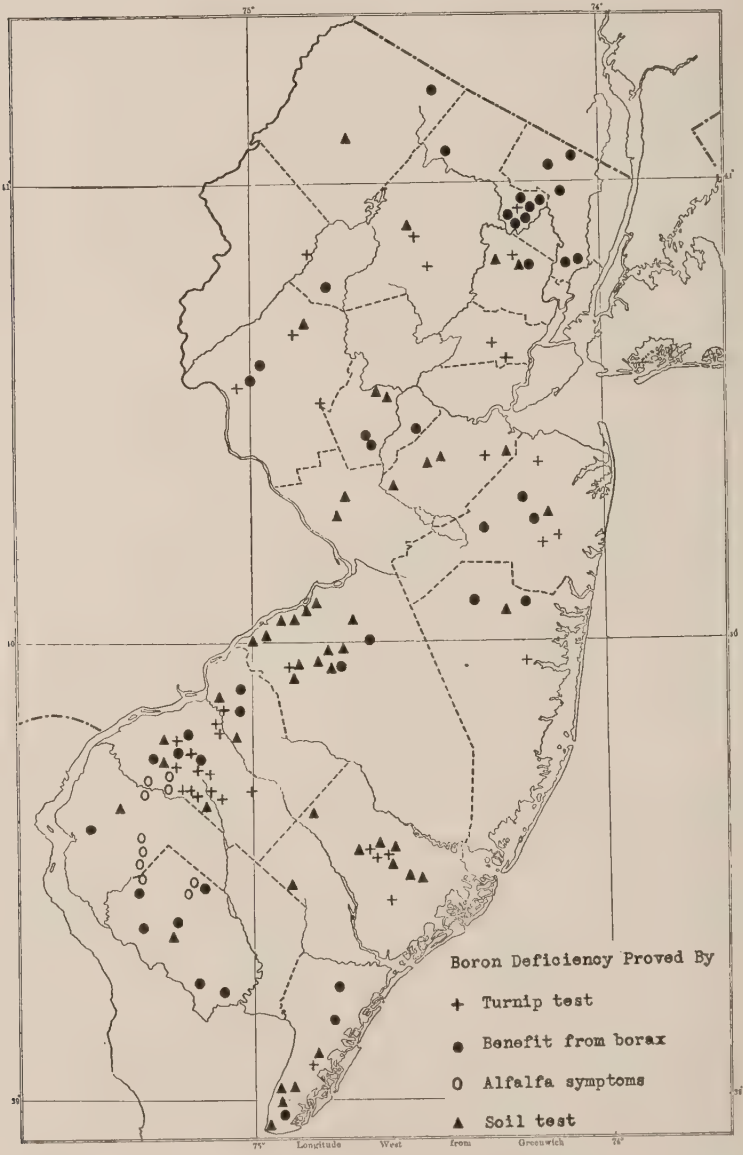

Fig. 3. Locations of New Jersey Farms on Which Soil Was Shown to Be Deficient in Boron. Much of Ocean County and the Eastern Part of Burlington County, the Area Along the Atlantic Coast Where no Symbols Are Shown, Is Covered with Sandy Soil That Is Not Being Used for Crop Production.

State has at least one case in which boron deficiency was evidenced by one of these four means of detection. This study did not include the peat soils in Warren and Bergen Counties, where farmers are regularly using borax to prevent cracked stems in celery.

Since sea water contains 4.5 p.p.m. boron, it is conceivable that the mist blowing in from the ocean could carry enough of this element to supply the needs of crops growing on nearby land, but there was no correlation between the incidence of boron-deficiency symptoms on crops and their nearness to the seacoast. One of the alfalfa fields that responded most strikingly to borax treatment is 3 to 4 miles from the ocean in three directions. The results of approximately 100 water-soluble boron determinations on Sassafras soils likewise showed no relation whatever between the boron content of the sampled areas and their distance from the coast.

Some Manufacturers Include Borax in Fertilizer Mixtures

It is known that certain fertilizer manufacturers add small amounts of borax to their mixtures.[8] But whether they do or not, these mixtures may contain small amounts of it as an impurity in the fertilizer materials. In order to obtain some information on the actual quantities of borax in the fertilizers that were being sold in the State, 55 samples, representing 14 companies, were obtained from the State Chemist during the summer of 1942. Analyses of these samples for their water-soluble boron yielded the data shown in table 16, when calculated in terms of borax.

TABLE 16

Borax per Ton in 55 Mixed Fertilizers in New Jersey in 1942

Number of Samples	B Content as Borax
	lbs.
4	0.00
10	0.01 to 0.25
13	0.26 to 0.50
12	0.51 to 1.00
6	1.01 to 2.00
9	2.01 to 4.00
1	5.52

It seems probable that fertilizers containing boron equivalent to more than 1 pound of borax per ton have had some of this substance added to the mixture. It will be noted that several grades of fertilizer contained more than 3 pounds of borax per ton, and that one of these showed a content of 5.52 pounds.

Added Borax Remains Water-Soluble in Mixed Fertilizers

A test was made to determine the extent to which 20 per cent superphosphate and 5-10-5 mixtures, prepared from superphosphate, sulfate of ammonia, uramon, and muriate of potash, reduced the solubility of admixed

[8] One of the largest fertilizer manufacturers operating in the State has been adding 5 pounds of borax to every ton of fertilizer sold for a number of years.

borax. The content of soluble boron of each mixture was determined immediately after mixing, and again 11 weeks later. The results, shown in table 17, indicate that some of the boron is fixed immediately when borax is mixed with superphosphate but that no further fixation occurred on standing. The borax was completely recovered from both the 5-10-5 mixtures, however, by water extraction.

Table 17

Recovery of Borax From Fertilizer Mixtures

Fertilizer*	Added per ton	Recovered after mixing	Recovered after 11 weeks
	lbs.	*lbs.*	*lbs.*
1. 20% Superphosphate	5	3.96	4.00
2. 5-10-5	5	5.32	5.02
3. 5-10-5	5	4.95	5.51

*Fertilizers 2 and 3 were identical, except that 3 contained enough dolomitic limestone to neutralize the potential acidity of the mixture.

Needed Borax May Be Added to Fertilizer

The results of the study of the boron needs of the soils and crops in New Jersey indicate that borax must be applied on a considerable area of land and for a considerable variety of crops if maximum yields are to be obtained. Eight of the 20 important soil types studied were found to be deficient in boron. Of these eight, the deficiency was most widespread in Sassafras soils. Of the important crop plants in the State, alfalfa, clover, spinach, celery, cabbage, cauliflower, tomatoes, and the root crops—turnips, rutabagas, table beets, and radishes—are most likely to need extra supplies of this element.

The rate of application of borax depends on the nature of the soil, the kind of crop to be grown, and the degree of deficiency of boron. The problem is further complicated by the sensitiveness of certain plants to any excess of the element. Thus injury from an overdose of borax may occur with such crops as snapbeans, limas, soybeans, and sweet potatoes, particularly when grown on the sandier types of soil. With all these facts in mind, it is recommended that, where borax is known to be needed, it be applied at the rate of 10 pounds per acre, if the soil is sandy, and 20 pounds per acre, if the soil is of the loam type. For crops like alfalfa that are to remain on the land for some years, the initial application may well be at the rate of 30 pounds per acre on the heavier types of soil, with supplemental top-dressings of 20 pounds per acre as required. In cases of severe deficiency, such as frequently occurs with turnips, rutabagas, and table beets, the rate of application of borax may have to be increased to double these amounts. If the material is used at these higher rates, it should be broadcast, well in advance of planting, and should be thoroughly worked into the soil. At ordinary rates of application, however, the borax can be mixed with the fertilizer, which can then be applied by whatever method is normally employed.

A convenient means of applying small amounts of borax separately from the fertilizer is by the use of the reinforced cyclone hand-seeder, which can be set to deliver amounts as small as 5 pounds per acre. Another method consists in diluting the borax with sand before broadcasting it. The most satisfactory system is to have the material mixed with the regular fertilizer at the factory.

To insure a fair supply of boron in all soils, *it is believed that about 5 pounds of borax*[9] *might well be mixed with every ton of fertilizer sold in the State.* If such an amount of borax is included regularly in the fertilizer, it is possible that a lack of boron will never be a limiting factor in crop production on many farms.

Methods Employed in This Study

Water-Soluble Boron in Soils

The water-soluble boron was determined in all of these experiments by placing a 100-gm. air-dried soil sample in a 500-ml. boron-free flask. (Corning No. 728 boron-free glassware was used throughout). To the soil was added 200 ml. boiling water; the suspension was shaken intermittently for 25 minutes and allowed to stand 10 minutes. The supernatant liquid was decanted into a 250-ml. flask, 0.1 gm. solid anhydrous calcium chloride being added, and allowed to settle 5 minutes before a 100-ml. aliquot was filtered into a beaker. The filtrate was made slightly alkaline to litmus with a 10 per cent solution of potassium carbonate after which it was evaporated to a volume of 50 ml. A 20-ml. aliquot was then transferred to an evaporating dish, taken to dryness, and ignited at 600° C. in a muffle for 3 hours. The ignited sample was taken up in 5-ml. of 0.36 *N* sulfuric acid. A 1-ml. aliquot of this solution was then placed in a comparison vial, 10 ml. of concentrated sulfuric acid-quinalizarin solution was added, and the vials were stoppered immediately. After standing at least 30 minutes, the boron content was determined by comparing with a set of standards prepared according to the method of Berger and Truog.[10]

Total Boron in Soils

A modification of the Wherry and Chapin procedure was used as follows: 5 gm. of finely pulverized soil was intimately mixed and transferred to a large platinum crucible. This was placed in a cold muffle furnace, and the temperature was raised to 900-950° C. The red-hot melt was poured into a large platinum dish floating on cold water. The dish was immediately rotated, in order to spread the melt into a thin layer. When cold, the melt was broken into small pieces by means of a mortar and pestle and transferred to a 250-ml. Erlenmeyer flask. The platinum crucible was cleaned by means of hot water and a policeman, all the liquid being poured into the Erlenmeyer flask. The final volume of liquid in the flask was about 50-60 ml.

[9]Borax retails at from 4 to 5 cents a pound.

[10]Details of this method, with some improvements, can be found in a paper presented by the senior author as a part of the Boron Symposium included among the "Selected References" on page 26.

This was allowed to stand overnight, or it was shaken in a shaking machine until all the melt had disintegrated. Slowly and cautiously, 29 ml. of conc. HCl was added, and the solution was put back on the shaking machine for 5-10 minutes. Small increments of $CaCO_3$ (reagent grade) were slowly added until the solution became alkaline and all iron and aluminum silicates had precipitated out. The presence of an excess of $CaCO_3$ was found to be essential. The flask was attached to a reflux condenser, the inner tube of which was made of boron-free glass. The solution was cautiously brought to boil on a low flame and refluxed for 10-15 minutes. The flame was removed, the stopper loosened from the flask, and the reflux tube washed down with distilled water. The suspension was poured onto a Büchner funnel containing a large filter paper that came up around the sides. The precipitate was then sucked dry and washed three or four times with hot distilled water, the precipiate being sucked dry each time. The liquid was returned to a 250-ml. beaker of boron-free glass and evaporated on a slow hot plate to slightly less than 100 ml. It was then cooled, made to exactly 100 ml., and transferred to a boron-free flask. One ml. of this solution, equivalent to 0.05 gm. of soil, was used for the determination of boron by the colorimetric quinalizarin method. From this point, the procedure was the same as that for water-soluble boron.

Total Boron in Plants

The boron content of the plant material was determined by the quinalizarin method of Berger and Truog.

Water-Soluble Boron in Fertilizers

The A. O. A. C. method for determining water-soluble boron in fertilizers was followed.

Boron-Fixing Power of Soil

The boron-fixing power of the 20 soils was measured by exposing them to a stock solution of borax (100 mgm. borax per liter). One hundred milliliters of the stock borax solution was added to 100 gm. air-dried soil, in a boron-free flask, shaken every hour for 16 hours, and allowed to stand 72 hours. The supernatant liquid was then analyzed for its boron content by the quinalizarin procedure. The amount of boron fixed by the soil was the difference between the boron content of the supernatant liquid and that of the original borax stock solution.

Field Technique

Where yield data such as are shown in tables 9 to 12 were obtained, the treatments were made in replicate, and representative areas were harvested from both the treated and the untreated portions of the field, the averages of the replicates being recorded. The data are dependable for the particular field and treatment.

In the more general survey of the boron needs of the soils of the State, the tests consisted in applying borax to either a ½-acre or a 1-acre plot near the middle of one side of a field and noting the effect, if any, on the growth

and appearance of the crop, in comparison with that of the surrounding untreated area. Unless effects that were readily apparent to the eye were noted, no credit was given to the borax. It is quite evident, therefore, that this report minimizes the need for boron rather than exaggerates it.

Summary and Conclusions

Turnips showed typical symptoms of boron deficiency on 42 of 156 farms on which they were sown for test purposes. These symptoms consist of dark-brown, water-soaked areas in the flesh of the turnips.

Definite crop response was obtained from the use of borax on 12 per cent of 350 widely distributed farms on which test plots were established.

Based on both laboratory and greenhouse tests, a water-soluble boron content of 0.35 p.p.m. of air-dry soil was set as the dividing line between boron-deficient and boron-adequate soils.

Of 200 soil samples chosen from an equal number of New Jersey farms and submitted to laboratory test, 88 were found to be in the boron-deficient group.

Of representative samples of 20 important soil types under special study at the Experiment Station, 8 were found to be deficient in boron.

Crops growing on well-limed soils were found to be more responsive to borax treatments than those on very acid soils. Raising the pH of acid soils had little effect on their content of water-soluble boron.

Loam and silt loam soils were shown to fix a great deal more boron than the sands and sandy loams, and crops growing on the heavier soils were less easily injured by heavy applications of borax.

From 75 to 85 per cent of a 20-pound-per-acre application of borax was washed out of 7-inch depths of four soil types by leaching them with an amount of water equivalent to one-fourth the average annual rainfall of the State.

The amount of water-soluble boron in soils was materially increased by the addition of green manures. Such organic materials as straw, manure, and cottonseed meal contained very little boron, however, and a good many tons of them would have to be added to the soil to supply as much of this element as does 10 pounds of borax.

Marked increases in the yield of carrots, spinach, clover seed, and alfalfa were obtained by the use of 10- to 40-pound-per-acre applications of borax to the soil.

Boron deficiency, as indicated by "yellows," was found to be common on the alfalfa fields in southern New Jersey.

Alfalfa hay contained boron equivalent to nearly 2 pounds of borax per ton, when grown on soils that were adequately supplied with the element.

A typical case of boron deficiency on Dutchess, Rome, and McIntosh apples was found in an orchard in Passaic County.

The Sassafras soils of southern New Jersey were shown to be conspicuously deficient in boron, whereas the Collington soils were very well supplied with the element. Crops growing on Lakewood, Penn, Gloucester, Mer-

rimac, and Wethersfield soils were frequently benefited by borax treatments, but those on the Dutchess, Washington, Dover, and Chester series were not.

Of the important crop plants, alfalfa, clover, spinach, celery, cabbage, cauliflower, tomatoes, turnips, rutabagas, beets, carrots, and radishes are most likely to need extra boron. Typical symptoms of boron deficiency have been observed on all of these crops at various locations over the State.

Snapbeans, limas, soybeans, and sweet potatoes are extremely sensitive to an overdose of borax, especially when growing on the sandier soils.

At least one case of boron deficiency was found in every county in the State and, in Gloucester County, 23 such cases were observed.

Of the 55 grades of fertilizer offered for sale by 14 companies operating in New Jersey in 1942, 51 contained boron. The highest content of boron found in any brand was equivalent to 5.52 pounds of borax per ton.

It is suggested that to all fertilizers sold in the State about 5 pounds of borax per ton be added as a means of maintaining a fair supply of boron in the soil. In areas of marked deficiency, however, and for such high-boron-requirement crops as alfalfa, clover, beets, turnips, celery, and cauliflower, heavier applications may be required.

Great care must be exercised not to exceed the recommended rates of application of borax.

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